Agricultural Land Markets – Efficiency and Regulation

Maizification of the Landscape for Biogas Production? Identifying the Likelihood of Silage Maize for Biogas in Brandenburg from 2008-2018

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FORLand-Working Paper 16 (2019)

Published by
DFG Research Unit 2569 FORLand, Humboldt-Universität zu Berlin
Unter den Linden 6, D-10099 Berlin
https://www.forland.hu-berlin.de

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December 2019

Abstract

The development of biogas production in Germany has reshaped agricultural land use and production schemes since the implementation of the Renewable Energy Sources Act in 2000. It is associated with a widespread introduction of silage maize as a major substrate. While it contributes significantly to the renewable energy production, intensive maize-for-biogas production comes at the expense of loss of area for food production, is associated with negative ecological effects due to intensive and large-area monoculture, and is also associated with an increase in land prices. However, due to missing data, little is known about the plot-based distribution and development of silage maize for biogas production and, therefore, the local effects remain largely unstudied. This paper aims to identify the plot-level based likelihood of silage maize cultivated for biogas production in the Brandenburg region of Germany from 2008 through 2018. For this ongoing study, we developed and applied a spatially explicit multicriteria approach using plot-level land use information from Integrated Administration and Control System (IACS) data and additional datasets on biogas plants. Our initial results show that within the 10 years of this study, the area which was most likely used for biogas silage maize production has tripled. We also find biogas silage maize production has been concentrated in the northwest and central-east of the region, and we identified distinct silage maize hotspots within the area. To the knowledge of the authors, this is the first attempt at biogas production. From our study, we can derive some of the spatially explicit effects of the Renewable Energy Sources Act on local land use dynamics over time. This may be an important asset for comparative and future studies on the effects of policy-driven land use changes on ecological and land price outcomes which will be subject of further analyses.

Keywords: Biogas, biogas silage maize, maizification, multicriteria approach, AHP, IACS, land use

JEL codes: Q24, Q28

Acknowledgements

We thank the DFG for funding this work in the research unit FOR 2569 "Agricultural Land Markets - Efficiency and Regulation". We also thank Philipp Grundmann and Leticia Hissa for comments and the Landesamt für Ländliche Entwicklung, Landwirtschaft und Flurneuordnung (LELF) for providing the IACS data.

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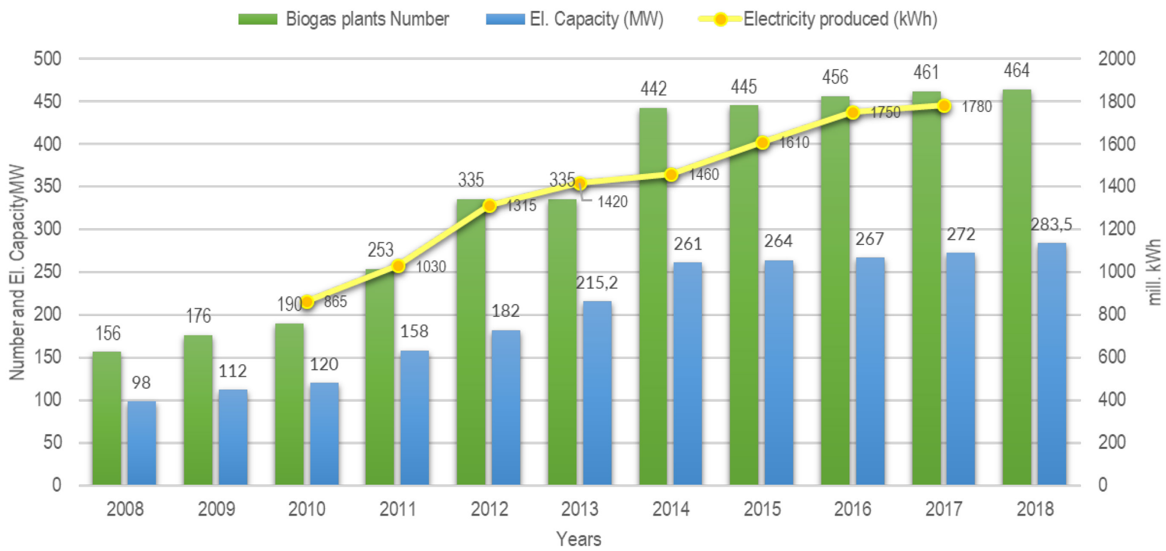
1 Introduction

In the last few decades, renewable energy has been discussed worldwide as one of the pillars of climate protection policies (Demirbas and Demirbas, 2007). Since 2000, Germany has been promoting the transition to renewable energy through environmental policies under the Renewable Energy Sources Act (Erneuerbare Energien Gesetz, or EEG), which guarantees a corresponding payment (feed-in tariff) for 20 years for each kilowatt hour (kWh) produced by a renewable energy source, depending on the size, location and type of renewable energy source (Grundmann et al., 2012; Heinrichs and Michelsen, 2014; Laird and Stefes, 2009). As a result, the expansion of and investment in renewable energy sources such as wind, solar and biomass have experienced a huge growth since 2000 with an even higher uptake than expected (Quitzow et al., 2016). Agricultural bioenergy has been considered an important contributor to global renewable energy production (Sims et al., 2006) because of its competitive advantage as it does not depend on solar light or wind power (UBA, 2013).

This study focuses on agricultural bioenergy production, which refers to fuel or electricity generated from biogas plants (Grundmann et al., 2012). The expansion of the biogas plants has led to large-scale changes in agricultural land use schemes in Germany (Offermann et al., 2010). More than 87% of the biogas plants run on energy crops, agricultural residue, and manure (Torrijos, 2016). Among these, the energy output varies with the starting material (i.e., type and quality) on average between 5.5 to 6.25 kWh per standard cubic metre (Geitmann, 2012). The biogas yield from maize is up to eight times higher than manure (Weiland, 2010). Consequently, silage maize represents 70% of the biogas input for energy crops (FNR, 2018; Grundmann et al., 2012) and contributes 56% of the total biogas energy production (DBFZ, 2015; Hutňan, 2016).

Biogas production in Germany started in the 90s with the availability of the respective technological know-how, the 1992 permission by the Common Agricultural Practice (CAP) to cultivate crops for energy production, and the environmental institutionalism at that time (Geitmann, 2012; Torrijos, 2016; Venghaus and Acosta, 2018). This condition was endured by the EEG implementation in 2000 and the amendment in 2004, leading to an increase in both the number and the average of biogas plant capacity. Germany rapidly became the leading biogas producer in Europe. Biogas installations increased at a rate of 450 plants per year in 2004, and 1,000 per year in 2009, accounting for 62% of the European biogas plants in 2013 (Appel et al., 2016; Torrijos, 2016). One of the most important states in Germany for biogas production is Brandenburg, where the number of biogas plants have increased substantially (see Figure 1). From 156 biogas plants and an electricity capacity of 98 MW in 2008, it increased nearly threefold to 442 biogas plants and 261 MW by 2014. Since then, the increase in number of plants and electricity capacity has slowed. The electricity produced has consequently also increased tremendously and has continued to increase after 2014. In 2016, biogas provided over 8,2% of the gross electricity consumption in Brandenburg, thus accounting for over 47% of the biomass electricity production of the region (AEE, 2018).

Figure 1: Development of number of biogas plants, their electric capacity and the electricity produced in Brandenburg from 2008 to 2018.



Data sources: AEE (2018), DBFZ (2017), Bnetz (2019)

With the increase in the biogas sector, large opportunities in agricultural management schemes came along that led to a critical discussion of the benefits of the large-scale introduction of biogas. First of all, studies point towards the differences in agricultural land use and in particular to the expansion of maize monocultures on large areas, referred to as *Vermaisung* (maizification) of landscapes (Karpenstein-Machan and Weber, 2010). This is expected to be on par with intensification of crop production and less crop diversity on a plot (FNR, 2013), conversion of non-cropped biodiversity-rich land, negative influence on soil fertility, reduction of farmland biodiversity (Pedroli et al., 2013; Sauerbrei et al., 2014), high nitrogen content followed by nitrogen spill-overs (Lupp et al., 2014), and loss of aesthetic value (Huth et al., 2019). Moreover, the use of land for energy crop production comes at the expense of loss of land use for food production (Grundmann and Klauss, 2014; Gutzler et al., 2015). Also, investors have been buying or leasing agricultural land for commercial purpose such as renewable energy projects, which could lead to additional competition for the land and influence farmland prices (Brendel, 2011; Myrna et al., 2019). There is evidence that along the EEG implementation, the benefits of the feed-in tariffs have been concentrating on larger farms (Appel et al., 2016). Lastly, the role of bioenergy in reducing greenhouse gas emissions in comparison to fossil fuels has been contested and bioenergy production has been identified as an important driver of indirect land-use change, meaning that land being used for bioenergy production in one place leads, for example, to deforestation and food production in another place (Gawel and Ludwig, 2011).

Therefore, albeit generally advantageous and profitable on one hand, energy crops have been put into question regarding their potential as a climate-change mitigation strategy due to the negative effects of monoculture expansion, or maizification, in Germany's countryside on the other hand. However, up to now, there is significant uncertainty in the information on quantity and location of plots that grow maize for biogas energy crop production. Some initial studies have analysed the expansion of energy crops but those refer to the aggregated district level (Gutzler et al. (2015) or to the state-wide level (MUGV, 2010). Comprehensive plot-based information on agricultural land use is available from the Integrated Administration and Control System (IACS) that offers annual data on agricultural land use as of May 31 of each year. However, from the data it cannot be inferred if the land was used for biogas production. Undoubtedly, there have been efforts to address the problem, for example, by including the new category “biogas silage maize” in the IACS since 2015, but since this is not obligatory, the data is not reliable and significantly underestimates the area.

Up to now, to the knowledge of the authors, there is no information available that shows on which plots maize has been cultivated for biogas production, nor is there a method to estimate the likelihood of maize for biogas production. This study therefore aims to identify the likelihood of maize plots being cultivated for biogas production and then analyse the temporal dynamics and spatial patterns of maize plots for biogas production in Brandenburg from 2008 to 2018.

The study suggests an initial multi-criteria approach to identify silage maize plots cultivated to produce energy for biogas across space and time. We focus on Brandenburg as one of the most important states of biogas production in Germany and on silage maize because it is one of the major sources of biogas production (from here on referred to as biogas silage maize). Thereby, this study provides initial plot-level data on the likelihood of biogas silage maize locations, extent, and spatial clusters as well as temporal dynamics. Such information may provide an important asset and starting point for analyses of EEG policy effects, and most importantly, for studying the environmental and economic effects of biogas silage maize such as soil erosion, decrease of biodiversity, and changes in land tenure and land prices.

2 Background: Statewide Policies and the EEG with Relevance to Biogas in Brandenburg

Several strategies have directly or indirectly benefited from the investment in biogas across different scales, from local to regional (for example, EU Renewable Energy Directive) and/or specific addressed technological aspects (Gas Network Access Ordinance) (MUGV, 2010). The two most important political strategies for the state of Brandenburg, the “Biomass Strategy of Brandenburg” (2010) and the “2030 Energy Strategy of the State of Brandenburg” (2012) both highlight the importance and future role of biogas production in Brandenburg to increase energy independence and to contribute to rural development, creating jobs and investments (MUGV, 2010) and to a sustainable region (MWE, 2012). According to the target of increasing the proportion of renewable energy, the primary energy consumption of renewable energy in 2030 is expected to be around 32% of the total Brandenburg outcome, and of the final energy consumption, 40% will remain in Brandenburg while the rest will be exported (MWE, 2012). Of the total renewable energy, 34% is contributed by biomass energy, the second source after wind energy. Likewise, up to 30% of arable land is expected to be used for material or energy biomass utilization (MWE, 2012).

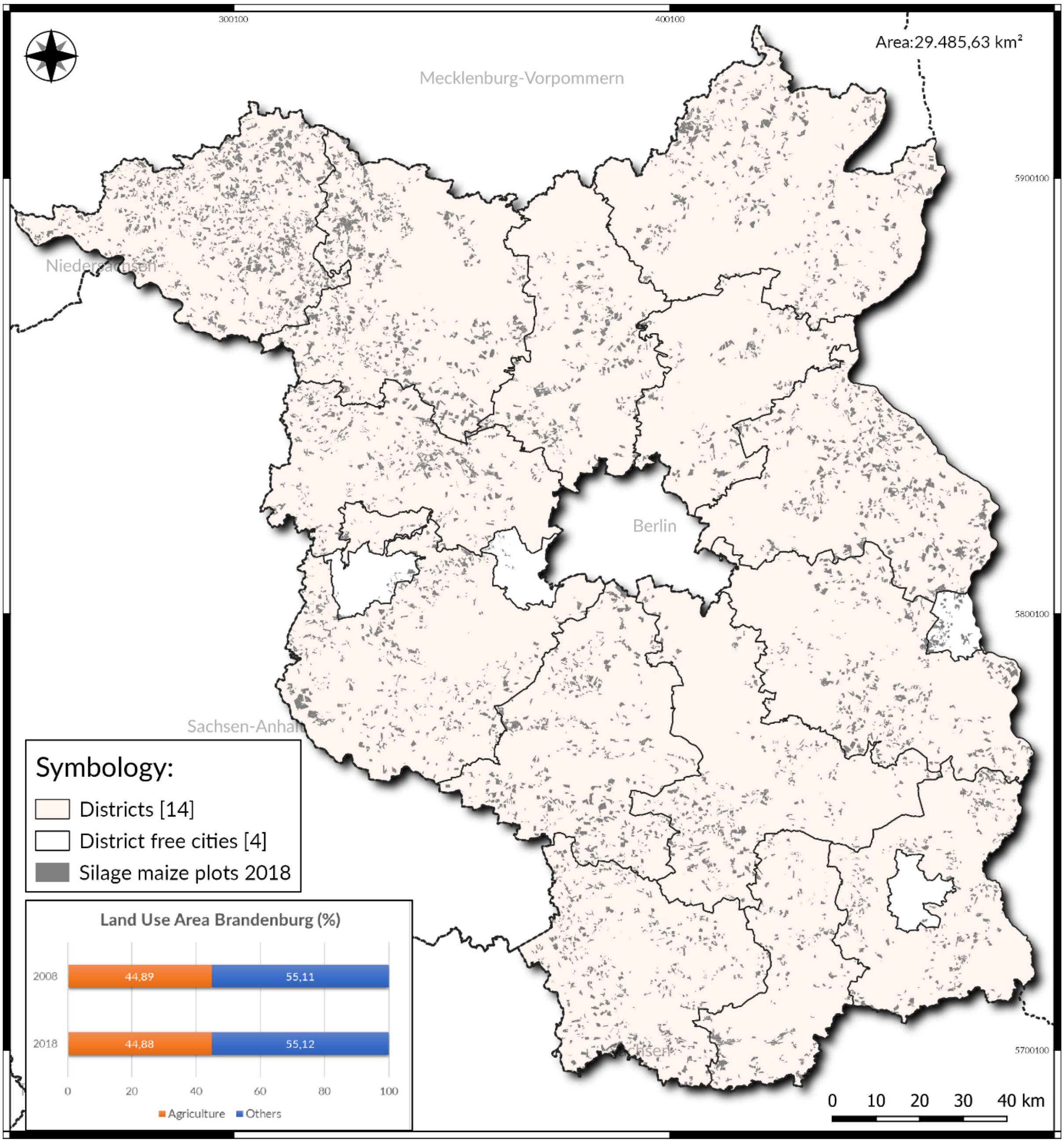
Most importantly, however, is the EEG, which played a major role in promoting biogas technology. The EEG offers specific feed-in tariffs for the biogas subtype. Since its implementation in 2000, the EEG has been updated five times (in 2004, 2009, 2012, 2014, and 2017) to address efficiency measures, technology improvements, and the incorporation of new steps in the energy transition to meet the renewable energy to the markets (BMWi, 2016; Torrijos, 2016). However, for the biogas branch of renewable energy, the adaptation has not been as expected in comparison to the other renewable energy feed-in tariffs since it is the most expensive and its price has not been falling, which led to putting its competitiveness into question (Appunn, 2016). The provision of the feed-in tariff is based on scientific studies to allow for profitability by using certain biomass and technology types (Couture and Gagnon, 2010; Fell, 2009; Klein et al., 2008; Lupp et al., 2014). It is categorized by the power plants size, dropping to higher output classes. This categorization has remained constant since the early implementation of the feed-in tariff, with an alteration in 2012, which included a new category to promote the use of manure (BMU, 2012). Furthermore, the basic payment is accompanied by other economic incentives such as bonuses for implementing sustainable techniques, input diversification, and landscape management (Lupp et al., 2014). With the EEG amendments in 2009, a decrease in support for large plants has been introduced, while smaller plants have received greater incentives. This was to introduce a rapid, quantitative increment of the biogas technology and to strengthen rural areas (Lupp et al., 2014; Torrijos, 2016). In 2012, all categories witnessed an increase in support, but from that year onwards a slight decrease in incentives came into force since it started this so-called second phase in promoting more greening alternatives such as alternative energy crops or residues with lower impacts over ecosystem. However, the effects have been slight in comparison with the first phase (2000 to 2012) (Lupp et al., 2014). This second phase is represented by the last two amendments (2014 and 2017). The first amendment made important changes as to take out the bonuses of Class I and Class II applied in 2012, to cut the feed-in tariffs for new plants, to establish an annual biomass construction limit of 100 MW, and to limit the fixed payment to 50% of the power that the biomass plants provide. Meanwhile, the rest was left to be adapted according to the market requirements (Appunn, 2016; BMEL, 2015; DBFZ, 2016). As a result, there was a significant drop in the construction of new biogas plants. Then, in the EEG's 2017 amendment the intention was to make this technology more competitive moving from fixed prices to auctions (BMWi, 2016). Theoretically, this would extend the possibility to invest in the biogas production development. Moreover, it was stated that the running biomass plants could extend their feed-in tariff for an additional 10 years with guaranteed feed-in tariffs to participate in auctions for follow-up financing (Appunn, 2016; MLUL, 2016). On the other hand, the 2017 amendment included new requirements for smaller actors as participating in tenders to finance the energy production, which is likely to favor large actors pursuing large-scale projects. Thus, the latest implementation is considered a setback for small and medium-sized farms and it is expected a decrease of the speed of deployment in renewable capacities (Schmid et al., 2017; UBA, 2019).

3 Materials and Methods

3.1 Study Area

We selected Brandenburg for this study because it holds large shares of agricultural land (45%), is one of the German states with highest increase rates in investments for renewable energy, and is expected to even become an energy exporter, as proposed by the State's Energy Strategy 2030 (MWE, 2012; MWEn, 2018). Located in the north-east of Germany, Brandenburg is the fifth largest German state. Its surface area is close to 29,640km², corresponding to 8,3% of the total Germany area. Of the 45% agricultural land, most is arable land (75%). Brandenburg comprises of 14 districts plus four free district cities, and it surrounds the German capital, Berlin (see Figure 2).

Figure 2: Agricultural and plot-level silage maize in Brandenburg region in 2018.



Data source: Amt für Statistik Brandenburg (AfSBB) (2019).

In Brandenburg, soil quality is low on average since almost two-thirds of it consists predominantly of sandy and sandy loamy soil (Gutzler et al., 2015). The climate is characterized by a warm humidity but the area has a comparably dry continental climate according to the Köppen classification (climate-data, 2019). The average rainfall in Brandenburg is 591mm/year^{-1} with June being the wettest month and October the driest month (weather-and-climate, 2019). This largely determines the type of crops that can be cultivated in the region, with rye as a main crop since it is the most suitable for the low-quality soil and long periods of drought (MIL, 2012). This is also true for Maize (*Zea Mays),* which is an annual plant with a C4 metabolism, being noticeably more water efficient than C3 crops and flexible to be cultivated in drier climates (Scott and Emery, 2016).

Agricultural practice in the regions is dominated by large-farm enterprises with an average size of 238 ha, which is four times the German average for farms (Gutzler et al., 2015). This is partly rooted in the German history of the German Democratic Republic, but also due to the unfavourable climate and soil conditions of the region (Venghaus and Acosta, 2018). Notwithstanding, after the reunification of Germany in 1990, the region experienced a rapid restructuration due to attractive EU funding programs. Therefore, the geographical conditions and farm structures may have positively influenced the state's successful energy policy program, which turned Brandenburg into a leading region for agri-ecological and agri-energy ventures in Europe (Venghaus and Acosta, 2018).

3.2 Data

We use two main datasets for this study: the IACS, Integrated Administration and Control System ("Integriertes Verwaltungs- und Kontrollsystem", InVeKoS) data to extract data on agricultural land use and livestock data per farm, and a dataset on biogas plants. In this study, IACS data is available for the Brandenburg region for the period between 2005 and 2018. IACS contains spatially explicit data at farm plot level, such as crop type and cultivated area, allowing analysis of the spatial patterns of land use. It provides data for all agricultural areas for which subsidies were applied for, likely representing all the agricultural land of the state. In this study, we only focus on the use of maize because it was prioritized by farmers as biomass substrate due to the best efficiency and cost structure (DBFZ, 2015; FNR, 2013), and, moreover, its management is generally known. It needs less plant protection than wheat, and it is self-compatible, allowing continuous cultivation (Brauer-Siebrecht et al., 2016; FNR, 2013). In addition, it has a desirable matter and methane content for biogas production (FNR, 2012). Though other energy crops such as sorghum or sunflowers have also been used as inputs for biogas plants in Brandenburg during the last decade, such crops have a small coverage area in the state and are less efficient (FNR, 2012). Thus, it can be stated that "maize is the sole crop for most of the biogas plants" (Grundmann et al., 2012, p. 122).

In this study, we select the following IACS codes for the analysis: 172 maize for biogas or maize (biogas) (called "Mais für Biogas or Mais (Biogas)" by IACS), 176 maize with wild boar hunting area and good agricultural and ecological conditions (referred to as "Mais mit Bejagungsschneise und gutem landwirtschaftlichen und ökologischen Zustand" by IACS), 177 maize with wild boar hunting area (called "Mais mit Bejagungsschneise (Kulturpflanze)", or "Mais mit Blüh-und/oder Bejagungsschneisen" by IACS), 411 silage maize (referred to as "Silomais" or "Silomais (als Hauptfutter)" by IACS). Other types of maize namely corn maize and CCM (171), sugar maize (174), and mixes with other crops (175) were not selected.

Farm-level data from IACS was made available that allows to identify which plot belongs to which farm according to a unique number (BNR-ZD), and that reports the number of cattle, pigs, sheep, and poultry per farm from 2005 to 2018.

Data about active biogas plants for the years 2005-2018 was derived from datasets from EKS (2016) and the LfU (2019). It was assumed that biogas plants without classification used energy crops since their inclusion approximated the number of selected biogas plants to the data published by the Agentur für Erneuerbare Energien AEE (2018). As a result, around 85% of the biogas plants were selected for each year for the analysis in this study.

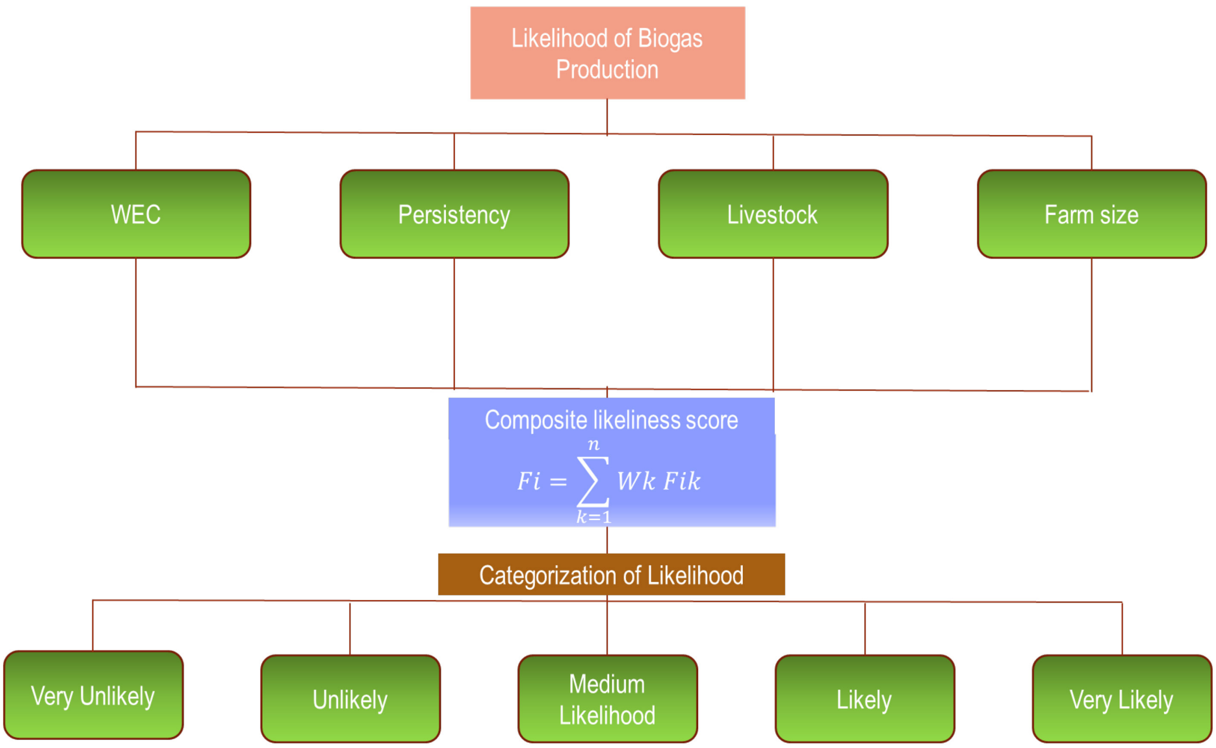
3.3 Methods

We applied a multi-criteria approach to analyse all the possible criteria available and to make an assertive decision for the likelihood of plots being used for biogas maize production based on hierarchy (Kumar et al., 2017; Malczewski, 2006). The approach allowed for the quantifying of “criteria based on its importance in presence of other objectives” (Kumar et al., 2017, p. 597). We adapted the multi-criteria land suitability approach from Tenerelli et al. (2007), and its evaluation (index score) to the likelihood for biogas production of each silage maize plot. To allow for a justified weighting process, which determines the importance of each variable for the model, we selected the Analytical Hierarchical Process (AHP) methodology that has been widely applied for multi-criteria analyses (Saaty, 1980). This method is used to solve complex problems through a mathematical process known as hierarchy superposition that helps to reduce the problem’s complexity and relies on quantitative data and expert opinions and providing relative weights of the variables, which can be subject to an evaluation of consistency (Castro et al., 2016).

3.3.1 Choice of Criteria

To identify the likelihood of maize for biogas production, we selected the following four criteria: the distance to and capacity of biogas plants (weighted electricity capacity of biogas plants, WEC), the permanency of maize use on a plot (persistency), the existence of livestock on a farm, and the farm size (see Figure 3).

Figure 3: Model to identify the likelihood of maize for biogas production



Below, the reasoning for the choice of variables and the respective data processing is explained in more detail as well as how a score index from 0 to 100 was assigned to each variable, following Tenerelli et al. (2007).

1) **Distance to and Capacity of Biogas Plants (WEC):** The reasoning for selecting this variable was that the distance to and capacity of a biogas plant determines to a large degree the likelihood of silage maize being used for biogas. This assumption was based on location theory (Christaller, 2006; Thünen, 1966; Weber, 1929) that tries to explain local land use decisions based upon differences in transport costs of inputs and outputs (Delzeit and Kellner, 2013). Thus, the site of a biogas plant was expected to be central or located relatively close to its substrates, aiming to minimize the feedstock transportation. Epp et al. (2008), for example, refer to a maximum distance of 15 km as a threshold for maize being produced for biogas plants due to the increasing transportation costs beyond that distance. Hence, we assumed that silage maize within a distance of less than 15 km to a biogas plant has a higher probability to be used as substrate for biogas plants. Moreover, we include the power capacity in the analysis following the example of (Lüker-Jans et al., 2017) because a larger biogas plant consumes more energy crops substrate than a smaller one. In Brandenburg, an average of 56% of the electricity produced in biogas plants comes from silage maize, therefore, using the power capacity data, it was assumed that around 56% of the power capacity of each plant comes from silages maize.
   Data Processing: We classified the biogas plants based on the feed-in tariff breaks of the EEGs and the spatial power capacity distribution in kW/km², e.g. with more than 4.5 MW power capacity a plant has a score of 100, expressed as over 20 kW/km². To determine the variable for a plot for each year, we applied a continuous spatial density kernel on a yearly basis. We created a raster using the biogas plants weighted by the energy capacity (see Appendix 1 for an example). As a result, we received area-wide, yearly raster layers with the weighted electric capacity that are then reclassified according to the previous scores (see Appendix 4).
2) **Persistency of Maize:** The reasoning here was that the continuous cultivation of silage maize on a plot suggests that it has been used for biogas production. The increasing demand of silage maize has risen the total hectares for silage maize cultivated which usually are cultivated as monoculture landscape (EEA, 2007; Herrmann, 2013). It is known that the farmers practice crop rotation in producing energy, however, to cope with the increasing demand for silage maize in Brandenburg (Appel et al., 2016), biogas farmers have reoriented their production maintaining silage maize for more than one year. It is also known that for different crop demand the crop mix has less biomass yield than single stands and optimized crop management (Bunzel et al., 2014).
   Data Processing: The spatiotemporal series of crop type cultivation data from IACS allowed us to calculate the persistency of maize cultivations for each plot between 2005-2018. We calculated the accumulative area proportion of a plot which was used as silage maize for the last 3 years. For example, if in 2008, a plot was cultivated with silage maize for the last 3 years, it will receive a score of 100, but if in 2006-2007 the plot was cultivated with rye, the score will be 86. We assumed an exponential relationship for the score (see Appendix 5).
3) **Livestock**: We considered livestock farming as a factor for positive correlation with biogas plant production because the biogas plants represent a good opportunity for farms to dispose their surplus manure in an environmentally friendly way and to produce their own energy (Geitmann, 2012; Lüker-Jans et al., 2017). Usually, biogas plants using manure as an input are located in the direct vicinity of livestock or dairy farms (Delzeit and Kellner, 2013, p. 44), where the utilization of manure as substrate in 2015 was around 43% (DBFZ, 2015). This situation has been undertaken since the EEG amendment of 2014, where this

proportion needed to be raised to reduce the amount of energy crops in biogas plants supporting the use of the livestock manure (BMJ, 2014). Thus, also the livestock farming is affected by the EEG amendments as is shown by Appel et al. (2016), where they project that, effectively, the EEG amendment of 2014 indirectly supports livestock production. Certainly, "The complementarity of biogas and livestock production causes an additional intensification of land use and more investments in livestock production" (Appel et al., 2016, p. 181). An important point is that we focused on cattle as a livestock unit because for Germany its manure constitutes the main manure substrate. In 2015, for example, it corresponded to approximately 70% of the manure substrate (DBFZ, 2015). Also, cattle contribute most to manure production accounting for 60% at a global scale (Herrero et al., 2009), although it does not have the highest biochemical methane potential (BML) as compared to volatile solids from the more frequent livestock units (including cattle, goats, pigs, horses, and poultry) (Kafle and Chen, 2016; Massé et al., 2011).

Data Processing: We calculated the number of heads of cattle per farm. The index score was defined that if a farm has cattle, there is a 50% possibility that its plots are cultivated with biogas silage maize, so is the plot receives a score of 50. The resting score is fulfilled when the growth head cattle rate is over 10% (score 75) or 15% (score 100). (see Appendix 6). The farm livestock data is in farm owner plot scale, instead of plot scale, i.e. several plots can be in 1 farm owner plot. Therefore, the same score, e.g. 50, was established in all the corresponding plots of a farm owner plot. The growth rate analysis takes into account two years backwards (see Appendix 2).

4) **Farm Size:** We expected from earlier findings that there is a positive relation between farm size and biogas plant size, showing that larger farm sizes have a greater propensity to cultivate biogas silage maize (Venghaus and Acosta, (2018). For example, Brendel (2011), establishes that for a biogas plant of 1,000 kW one should use around 550 ha of energy crops, while 200 ha of arable land is needed to operate a plant of 150 kW. Likewise, Venghaus and Acosta (2018) conclude that biogas farms in Brandenburg are substantially larger than non-biogas farms, with an average farm size of 1,564 ha. Reasons given are usually that to run a biogas plant, it is necessary to have a certain farm size and sufficient financial resources (Appel et al., 2016).

   Data Processing: We relied on the farm classification of Venghaus and Acosta (2018) and used the farm size information from IACS to classify the farms accordingly. The score index of this variable was applied accordingly (except cluster 4) (see Appendix 7). The spatial data scale is the same as in the livestock variable.

3.3.2 Calculation of Likelihood Scores Using the Analytical Hierarchical Process

The final likelihood score was broken down into five categories: 0-20: Very Unlikely; 20-40: Unlikely; 40-60: Medium Likelihood; 60-80: Likely; 80-100: Very Likely (see Figure 4). The categories Likely and Very Likely were further broken down into plots having biogas maize in the spatial cluster analysis.

To determine the likelihood score, we calculated the weights of each variable according to a pairwise comparison of the variables using the Analytical Hierarchical Process (AHP) similar to other studies based on literature and expert knowledge (Castro et al., 2016) (see Table 1).

Table 1: Values for the four variables in the AHP step

Factors	WEC	Persistency	Livestock	Farm size
WEC	1,00	7,00	5,00	3,00
Persistency	0,14	1,00	0,33	0,20
Livestock	0,20	3,00	1,00	0,33
Farm size	0,33	5,00	3,00	1,00

Applying the Saaty scale for a pairwise comparison among the variables (see Appendix 3), the WEC variable is expected to be the most important variable, because biogas plants depend strongly on energy crops close to the plants (Epp et al., 2008; Mitiku Teferra and Wubu, 2018). Persistency is assumed to have the least influence, due to existing crop rotation practices. Meanwhile, livestock might explain more than persistency, because of the complementarity of the biogas and livestock production, indicating at least a medium-term relation (Appel et al., 2016; Venghaus and Acosta, 2018). Lastly, farm size is expected to be the second important, because there is a direct relation between size and biogas production in Brandenburg (Venghaus and Acosta, 2018). In the final process we receive the weights: WEC: 56%; Persistency: 6%; Livestock: 12%; Farm Size: 26%.

3.3.3 Multi-Criteria and Spatiotemporal Pattern Analysis

We created a multi-criteria model workflow to automatize the complete process of data pre-processing as explained above and data analysis in the R environment, except for the WEC variable for which we used ArcGIS. First, the different variables are calculated iteratively for each selected plot with silage maize and each year from 2008-2018. The calculated values for the four variables are added to the corresponding plot-based IACS database. Finally, the multi-criteria approach is applied, exporting the score column with the likelihood of biogas production. The scripts and more details on the variable calculation that we had to limit in this paper due to space restrictions are available from the authors.

We then spatially depict the accumulated likelihood score values for the period examined. To complement the visual assessment of patterns of likelihood of biogas silage maize, we calculate the local indicator of spatial association (LISA; Anselin, 1995). The indicator quantifies the spatially explicit strength of associations between a variable and its neighbours, and returns high-high clusters, where plots with high values of likelihood of biogas silage maize is surrounded by neighbouring plots with high values of likelihood of biogas silage maize. The strength of the relationship is measured at the 0.05 level of statistical significance calculated by a Monte Carlo randomization procedure based on 999 permutations (using ArcGIS).

A quantitative verification and validation of the results was not possible due to the above stated lack of data, which was eventually the reason for this study. We circumvented this drawback by two approaches: relying on expert knowledge and literature analysis whenever possible (see chapter 3.3.1), and comparing our plot-based outcomes for likelihood of biogas silage maize with aggregated district-based outcomes of earlier studies.

4 Results and Discussion

Our multi-criteria approach allowed us to identify the likelihood of maize plots to be cultivated for biogas production and then analyse the temporal dynamics and the spatial distribution.

4.1 Dynamics in Likelihood of Biogas Silage maize in Brandenburg, 2008-2018

From our analysis, we find that the area of silage biogas maize in proportion to total agricultural area (according to AfSBB) has likely increased from 2,5 to 7,7% from 2008 to 2018 (see Table 2). Likewise, silage biogas maize of total silage likely represents more than the half (53%) in Brandenburg's in 2018.

Table 2: Proportions of biogas silage maize with total area of silage maize and total agriculture.

Years	Biogas silage maize/ silage maize area	Biogas silage maize/ total agriculture area
2008	25,58	2,50
2009	30,16	3,15
2010	35,87	4,24
2011	47,64	6,13
2012	48,6	6,31
2013	50,83	6,33
2014	50,89	6,77
2015	51,06	6,56
2016	52,2	7,13
2017	53,32	7,77
2018	52,81	7,68

A more detailed analysis of the different likelihood categories reveals a significant overall increase in biogas silage maize for the categories Very Likely and Likely from 2008 to 2011 (see Figure 4). In the years 2012 and 2013, the increase in proportion of plots with likely biogas silage maize slowed down and stabilized on a high level with about 101,000 ha in 2018, i.e. 50% of the silage maize area in Brandenburg was likely used for biogas production (see Table 3). While in 2008 the areas of Likely and Not Likely biogas silage maize was similar (33,000 ha versus 32,000 ha), in the following years, an increase in area likely for biogas silage maize production can be observed until reaching a peak in 2017.

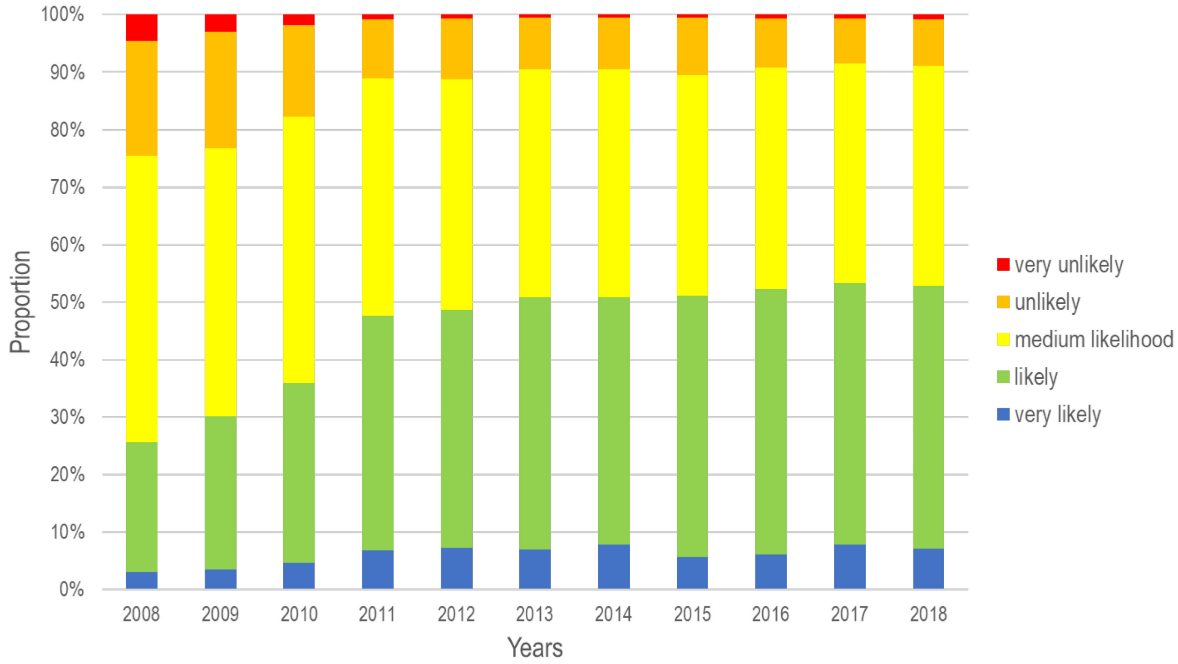
Table 3: Development in area of biogas silage maize (1000 ha).

For Biogas	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	Evolution Rate
Likeliness	33	41,8	56,17	80,8	83,2	83,1	89	86,7	93,7	102,7	101,6	**11,90**
Not Likeliness	31,7	32,2	27,8	18,7	19,2	15,6	16,7	17,8	16,4	16,4	17,2	**-5,93**
Total	129	138,6	156,6	169,6	171,2	163,5	174,9	169,8	179,5	192,6	192,4	**4,08**

Please note that for the total sum, the medium likelihood category is included while it is not shown here.

The evolution rate values confirm that biogas silage maize cultivation increased rapidly from 2008-2018 (11,9%), and at the same time, the likelihood of silage maize dedicated for other purposes decreased at a rate of 5,9%.

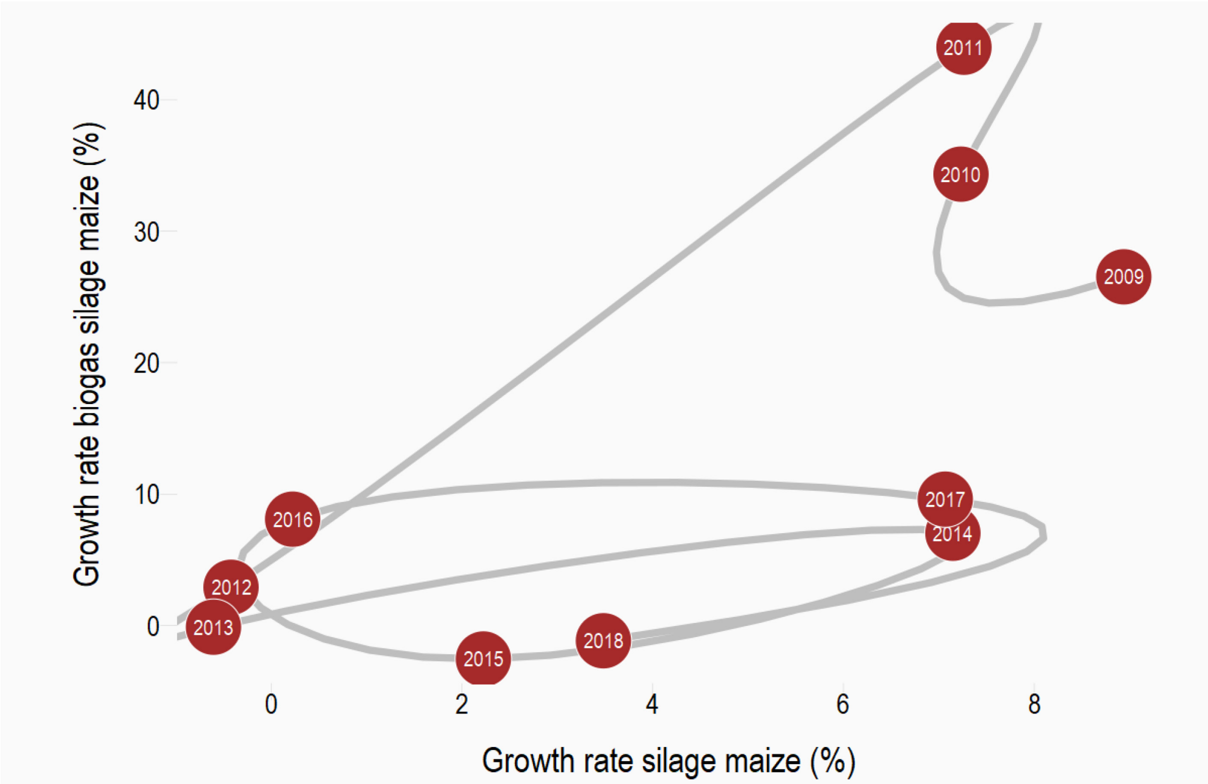
Figure 4: Overall changes in likelihood of biogas silage maize from 2008-2018



Comparing our findings with three existing studies, we find our values within reasonable range of the reported data. A study from MUGV (2010) indicates that overall, approximately 28% of the silage maize was used for biogas production, which is very close to the 35% that we identified in this study (see in Figure 4). As for 2011, AEE (2013) stated that 51,000 ha were used for biogas, which is significantly lower compared to the 80,000 ha found in this study. However, in contrast to this number, LELF (2019) approximates that around 95,000 to 100,000 ha were used for biogas production, confirming our findings of 101,000 ha that we identified in 2018.

Analysing these developments in the light of the EEG amendments of 2009, 2012, 2014, and 2017, a direct effect can be deduced. With the 2009 amendment, the correlation is palpable and the effect in terms of increase in area lasts for the following two years. Figure 5 elucidates the EEG's effects by comparing the yearly growth rate of biogas silage maize (y axis) with the yearly growth rate of the silage maize (x axis).

Figure 5: Amendments in the EEG and respective trends in biogas silage maize and silage maize for other uses from 2009-2018.



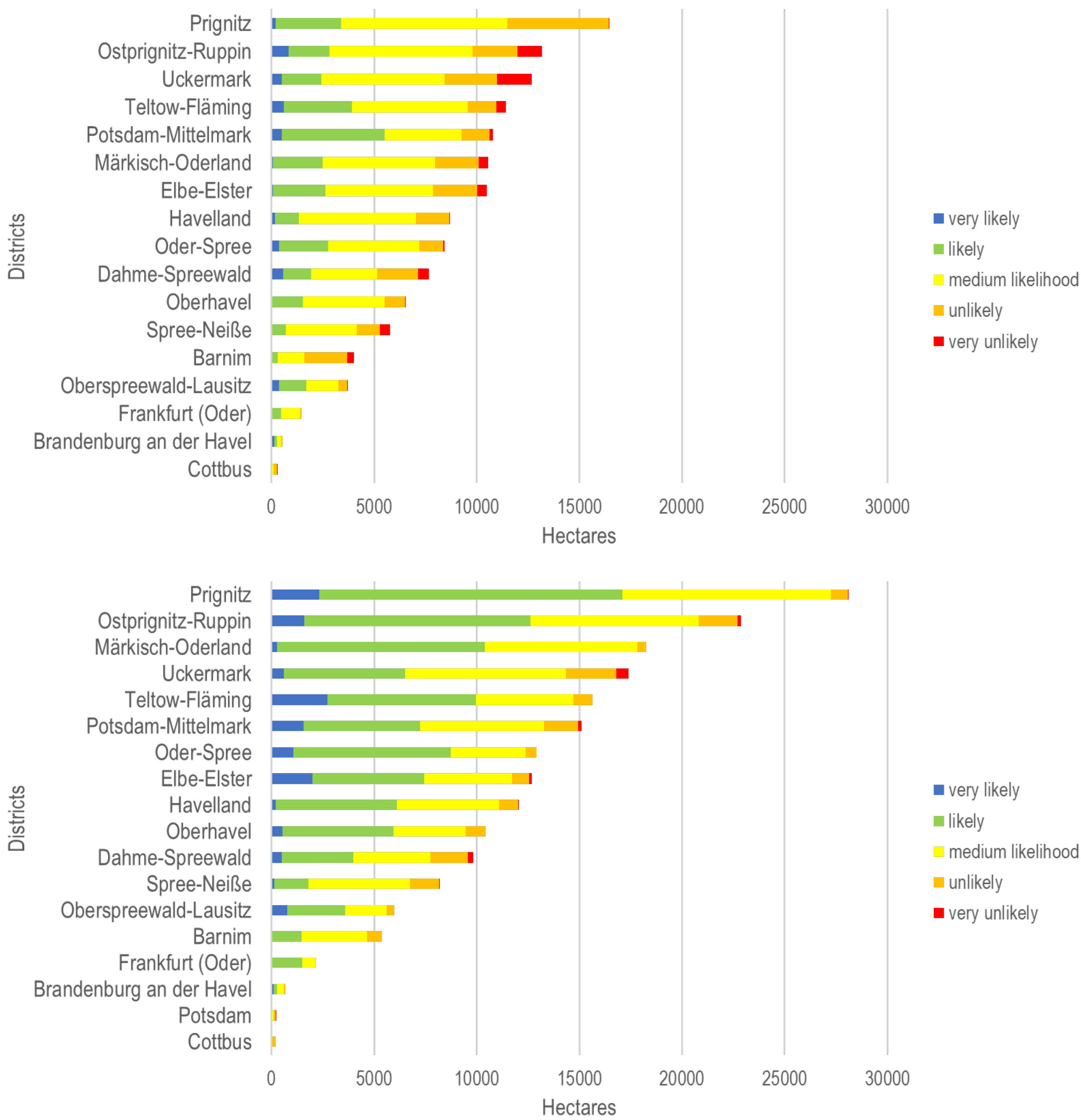
Please note different units of axes. Data Source: (AfSBB).

Both growth rates in the beginning of the time frame had high values on their respective axes but after the implementation of the 2009 EEG amendment, biogas silage maize increased more than silage maize for other purposes during 2009-2011. The latter even decreased from 2009 to 2013. Thus, a direct effect of the EEG on the increase in biogas silage maize can be attributed to this development. In the subsequent years (2012 -2013), there was a significant slowdown in both growth rates. This can be explained mainly by the silage maize cap as a result of the EEG amendment of 2012 (BMU, 2012). Moreover, the decrease in the growth rates may also be attributed to a lack of land access flexibility, the existence of investment thresholds (Reise et al., 2011), and external factors such as drought or price fluctuations (Grundmann et al., 2012). That means, the EEG amendment of 2012 has had the expected effect of decreasing the growth rate but with more effect on the total silage maize resulting even in a negative growth. The demand for biogas silage maize due the existing and newly built biogas plants, however, led to a continuous increase in biogas silage maize. In the following years, the pattern switched to become a circular relation and indicate a decrease in growth rates after the EEG amendments of 2014 and 2017, which were to reduce the amount of energy crops as substrate for biogas plants (BMJ, 2014; BMWi, 2017).

4.2 Spatial Variation in the Likelihood of Biogas Silage maize in Brandenburg

Figure 6 depicts the spatial distribution of the likelihood of biogas silage maize on the level of districts for 2008 and 2018.

Figure 6: Likelihood of biogas silage maize by district in 2008 (top) and 2018 (bottom)



Based on this data, it is clear that in 2008, biogas silage maize was likely cultivated more in the middle of Brandenburg, specifically in the districts Potsdam-Mittelmark and Teltow-Fläming (see Figure 7 for the location of those districts). Over the following years, this distribution likely changed rapidly and biogas silage maize cultivation moved towards the north of the region (Prignitz, Ostprignitz-Ruppin) where it increased the cultivation area but also decreased the cultivation of silage maize for other purposes. Through the years, this change was consolidated, being the main part of the region that was likely to produce biogas silage maize. Furthermore, some districts point towards particular developments, such as Märkisch-Oderland, which increased its biogas silage maize cultivation four times in a decade, moving from the sixth to the third place among districts in producing biogas silage maize in 2018. Similarly, Potsdam-Mittelmark was the most important producer of biogas silage maize in the beginning but over the years lost its importance.

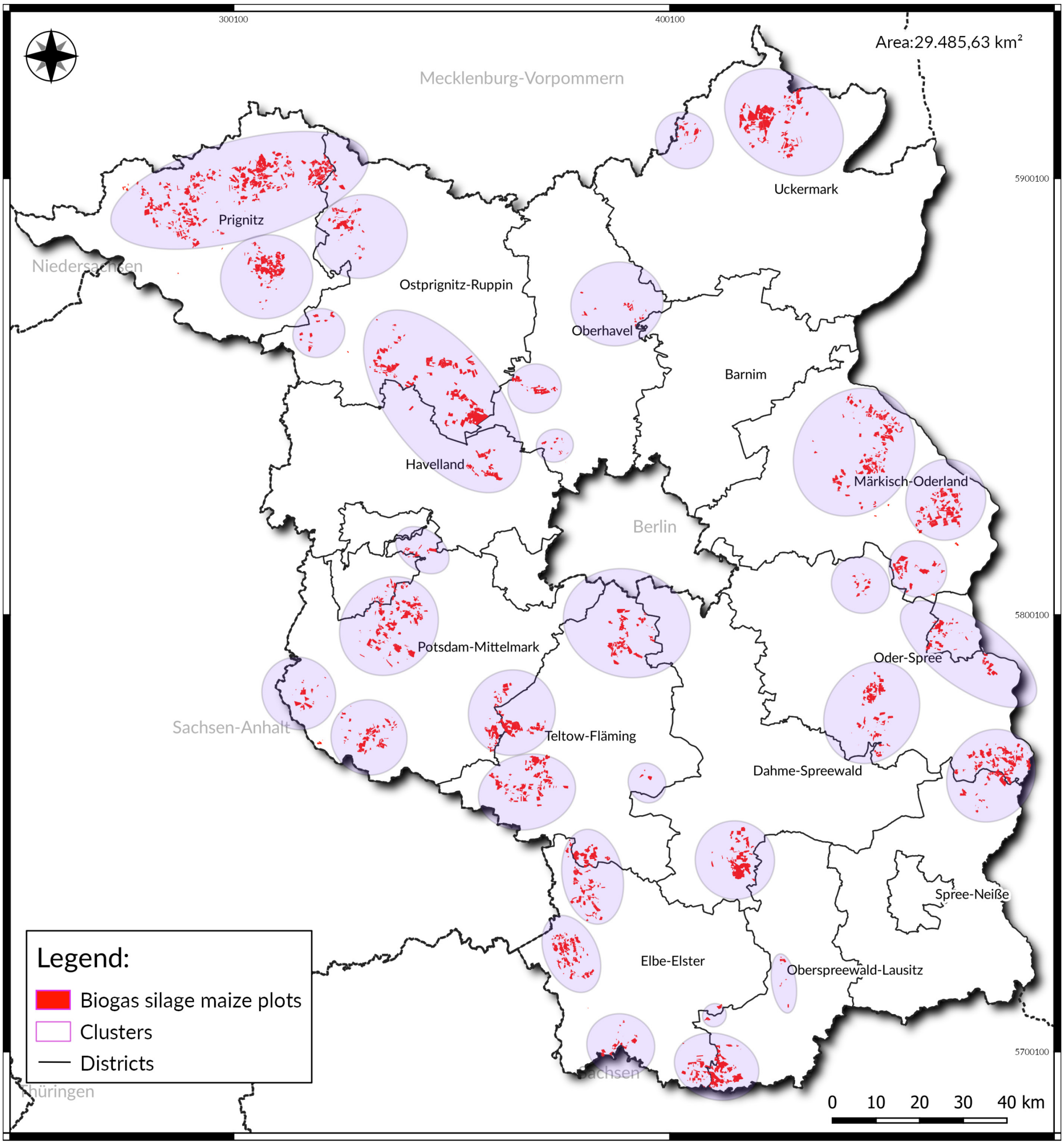
Interestingly, while from 2008-2011 the biogas silage maize cultivation likely increased in practically all the districts, from 2011-2018 the increase was mainly limited to the four districts of Prignitz, Ostprignitz-Ruppin, Uckermark, and Märkisch-Oderland. This suggests that these districts were specializing their silage maize cultivation for biogas production. Our plot-level analysis allowed for a more detailed analysis of spatial patterns and reveals that after 2011, several districts preferred a localization of biogas silage maize. Prignitz, for example, likely inclined to concentrate its biogas silage maize in the middle of the district. Similar spatial concentrations were identified for the district of Uckermark in the northwest of its territory and Ostprignitz-Ruppin, where the biogas silage maize plots were concentrated in the south of the territory, near the district of Prignitz. The spatial patterns hence show that the biogas silage maize cultivation shows very distinct patterns within a district based on the land management and not on the administrative boundaries, and that the plot-based analysis therefore adds important insights to a summarizing measure on the aggregated level of a district. As illustrated above, we identified a decelerated growth, which, however, does not indicate where the investments happened, or if they were concentrated to particular areas. Appel et al. (2016), point out that the number of actors involved could have been reduced by those with greater purchasing power. This might be one explanation for the spatial concentration identified in the state of Brandenburg.

In comparison with the districts which Gutzler et al. (2015) indicate as those with highest importance for electricity production from biogas we identify similar results, and can further detail the spatial distribution within these districts. We see, for example, that in Uckermark and Märkisch-Oderland there are more concentrated patterns while biogas silage maize clusters in Prignitz are more spread out. These distributions may respond to spatial conditions such as protected areas and soil conditions. In this study, we checked for the soil quality and found the plots with high likelihood of silage maize to be “not disadvantaged” as per MLUL (2018). This is remarkable since around 80% of the Brandenburg soil is classified as “disadvantaged.” Thus, our findings may suggest that the best soil conditions have been used to produce energy.

The spatial distribution that we see is most likely driven by the spatial patterns of the WEC variable that is derived from the location and power capacity of the existing biogas plants. With a weight of 56%, the WEC substantially influences the multi-criteria analysis, which also aligns with findings from existing studies. In general, in the clusters of the north-west and the central-east of the state, we find medium-sized biogas plants.

Finally, we identified hotspots of biogas silage maize for the accumulated values from 2008 to 2018 (see Figure 7). Of all the clusters, the largest cluster is located in the northwest. Meanwhile, in the south, the cluster is located beside the administrative regional limits, which can indicate that many biogas plants have been located there or in the neighbouring regions. The other clusters are distributed in the center of the state (both east and west) and an isolated cluster can be observed in Uckermark. This initial identification of spatial clusters or hotspots of biogas silage maize may have future potential for impact analyses such as on ecological effects and land prices.

Figure 7: Spatial clusters of biogas silage maize cultivation in Brandenburg, 2008-2018



4.3 Limitations

One limitation of this initial study is that there is no validation data available to test the presented approach since there is no plot-level data available on maize being produced for biogas. To circumvent this drawback, we relied extensively on existing literature on the topic and on expert knowledge to identify the variables, the scale and the weighting in the multi-criteria approach. We also compared our findings to existing data as far as possible. One possible future step may be to validate the results with expert interviews with farmers and stakeholders. Secondly, to develop a transparent, quantitative multi-criteria approach that can be applied at a plot-level every year for the entire state of Brandenburg requires a simplification of complex matters and depends heavily on the availability of data. We focused on the most important variables found in the existing literature but our approach could be augmented several ways, e.g., by including variables such as social networks production and social institutions (Bock und Polach et al., 2015; Venghaus and Acosta, 2018). Besides, for the WEC variable used in this study, we relied on intra-state values and did not account for neighbouring areas that could provide biogas silage maize for plants, or that have biogas plants which could influence the area of investigation. Thirdly, the process to determine the weights of the variables in the AHP process may be further qualified by including additional input from focus groups on top of the literature used and the expert knowledge. However, the purpose of selecting this methodology was to show the potential for identifying spatiotemporal dynamics affecting the likelihood of biogas silage maize cultivation in Brandenburg. The results can, of course, only approximate the reality. However, it exploits and explores the potential of the IACS data in combination with the data on biogas plants, linking energy production with the respective land use. IACS is the most complete and reliable dataset within agricultural data, combining a remarkable level of detail on space, time, and content in one dataset, and therefore being a crucial pillar for future policy modelling and a novel solution for the geographical science (Tóth and Kučas, 2016).

5 Conclusions

The initial outcomes of the study presented here identified the likelihood of biogas silage maize in the time frame 2008-2018 in Brandenburg using a multicriteria approach. We suggested a method for identifying the likelihood of the silage maize plots to be considered for biogas production by integrating four variables that determine if a plot with silage maize has been cultivated for biogas production within a year. We successfully applied this model in the case of Brandenburg, and found distinct temporal and spatial dynamics. First, we found a direct response between the likelihood of biogas silage maize production and the EEG amendments. Second, within the period studied, we found a tendency for increasing spatial clustering within certain districts (such as Prignitz or Ostprignitz-Ruppin), while others remained stable. We therefore conclude that the use of agricultural land for biogas production in Brandenburg is indeed thought provoking because the biogas silage maize likely corresponds to more than half of the total silage maize in Brandenburg since 2013, and it is spatially concentrated in biogas maize clusters. Undoubtedly, this has most likely influenced farmland management practices, land prices, and has had ecological effects on these areas.

The results may therefore be an important asset for future analyses since, to the knowledge of the authors, plot-level data on the likelihood of biogas silage maize did not exist prior to this study. Future studies may focus on aspects such as land price change, the effect of climate change on silage maize yield (Peichl et al., 2019) or the institutional context of biogas silage maize (Bock und Polach et al., 2015). Relating our findings with an in-depth analysis of the decision-making behaviour of farmers who invest in the bioenergy market (Reise et al., 2011) and validating the methodological assumptions with expert interviews may be a next step in the future.

Finally, we emphasize that the aim of this study was not to damage the image of the biogas production in the agricultural sector. In fact, the existence of biogas production in the countryside offers great possibilities. However, we agree with Theuerl et al. (2019) that the focus should be on improving the efficiency of biogas silage maize and addressing other substrates such as manure and bio garbage. We have been living in the age of adaptation to sustainable energy for a while. Now is the time to consolidate knowledge of this area, improve the efficiency of farming practices, and analyse the trade-offs and synergies between bioenergy and food production towards a more sustainable, spatially optimized agricultural land use.

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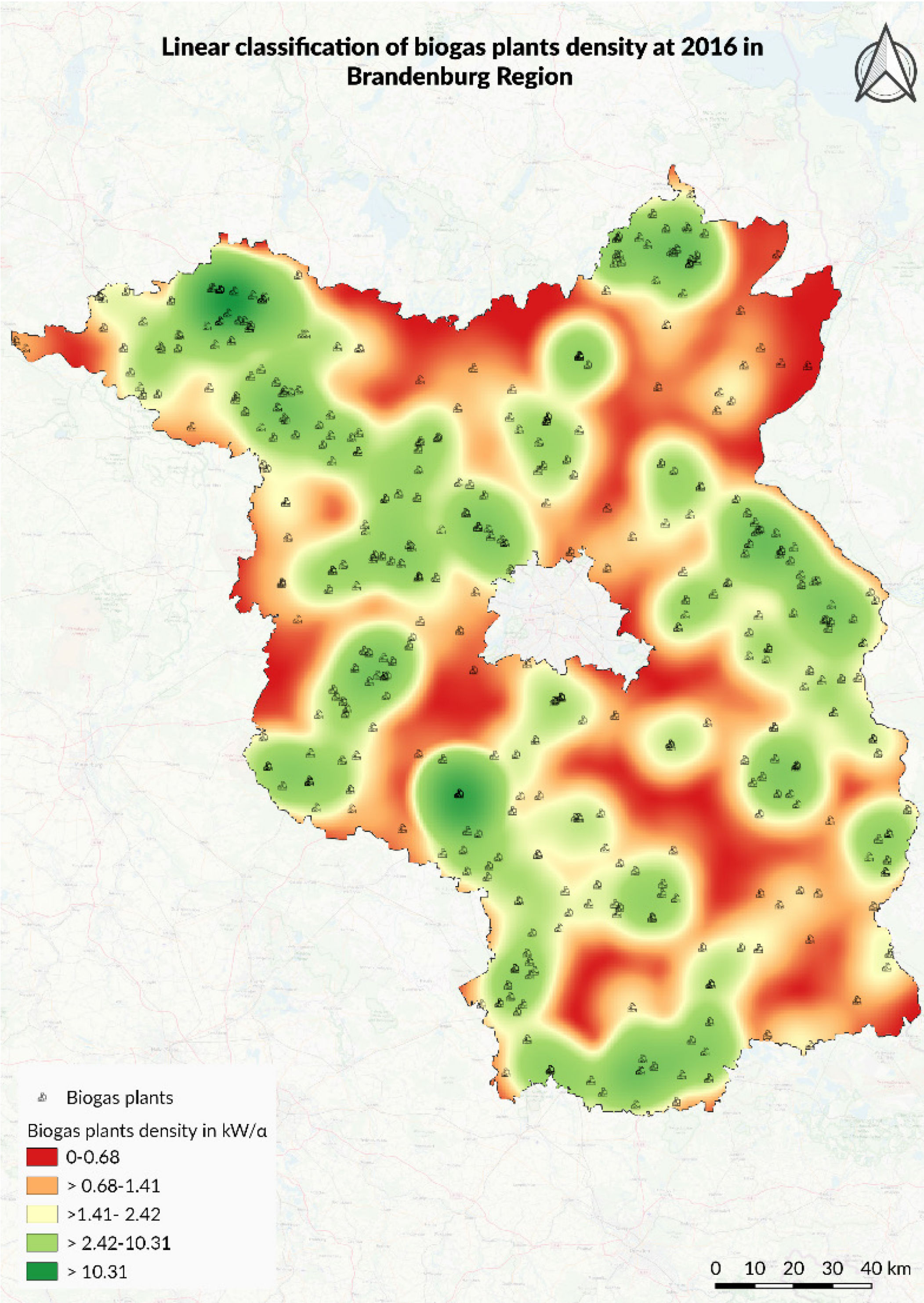
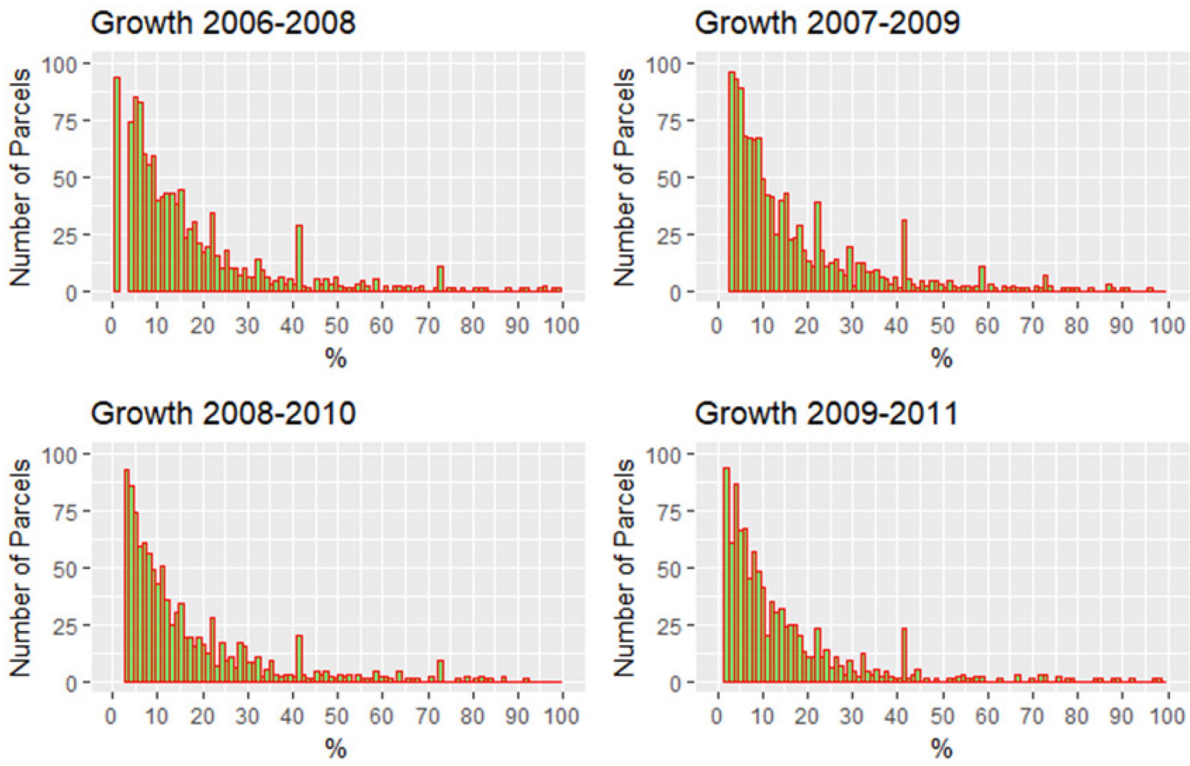
7 Appendix

Appendix 1: Capacity-weighted biogas plant density



Note: α = 706,85 km²

Appendix 2: Growth rate of head of cattle for the years 2008-2011 (including the 2 previous years for each target year).



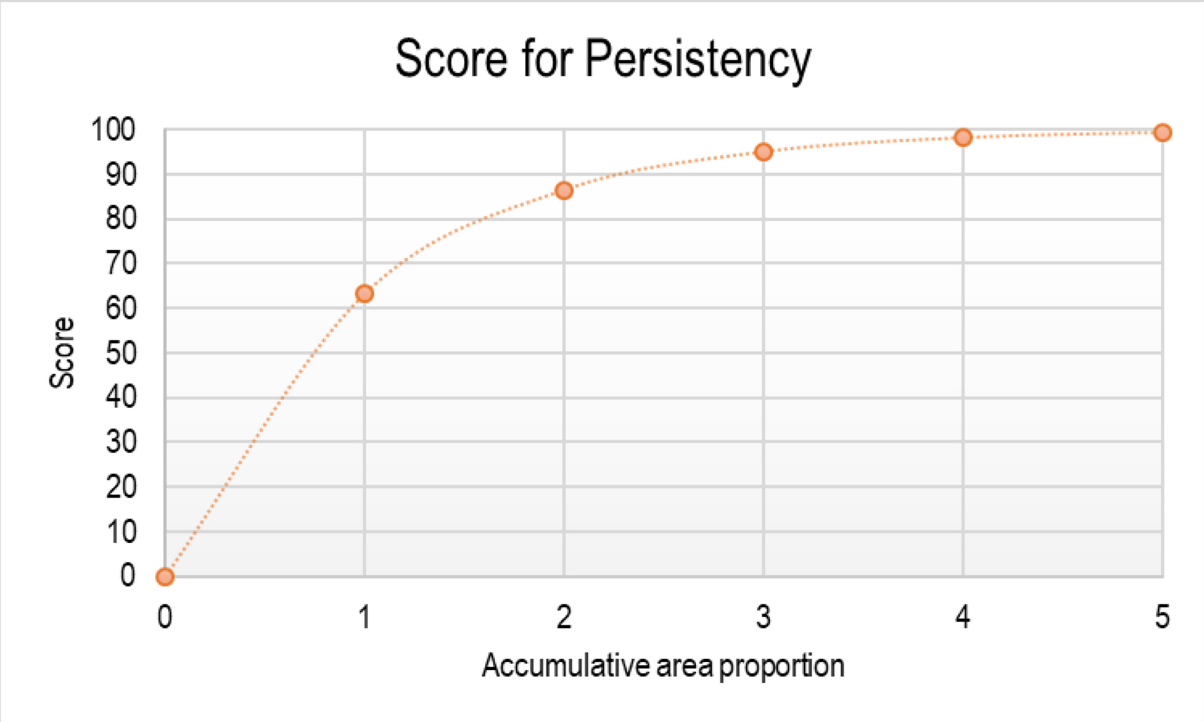
Appendix 3: Saaty scale

Value	Description
1	Equally important
3	Moderately more important
5	Strongly more important
7	Very strongly more important
9	Extremely more important

Appendix 4: WEC Score index

Class: WEC (kW/km²)	Score
>20	100
5-20	80
3.5-5	60
2-3.5	50
0.5-2	40
0.15-0.5	20
0-0.15	10
0	0

Appendix 5: Persistency Score index



Appendix 6: Livestock index score

Class: Livestock	Score
No cattle	0
Cattle	50
Cattle + growth 10% over 2 years	75
Cattle + growth 15% over 2 years	100

Appendix 7: Farm size index score

Class: Farm size (ha)	Score
<350	0
350<600	25
600-<1250	50
1250-<1550	75
>1550	100